GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL of ELECTRICAL and COMPUTER ENGINEERING

ECE 2025 Spring 2003
Lab #11: Two Convolution GUIs

Date: 2–8 April 2003

Tuesday Lab sections only: Start Lab #11 on 8-April. No Lab on 1-April-03 for L02, L04 and L08.

You should read the Pre-Lab section of the lab and do all the exercises in the Pre-Lab section before your assigned lab time. You **MUST** complete the online Pre-Post-Lab exercise on Web-CT at the beginning of your scheduled lab session. You can use MATLAB and also consult your lab report or any notes you might have, but you cannot discuss the exercises with any other students. You will have approximately 20 minutes at the beginning of your lab session to complete the online Pre-Post-Lab exercise. The Pre-Post-Lab exercise for this lab includes some questions about concepts from the previous Lab report as well as questions on the Pre-Lab section of this lab.

The Warm-up section of each lab must be completed **during your assigned Lab time** and the steps marked *Instructor Verification* must also be signed off **during the lab time**. After completing the warm-up section, turn in the verification sheet to your TA.

Forgeries and plagiarism are a violation of the honor code and will be referred to the Dean of Students for disciplinary action. You are allowed to discuss lab exercises with other students and you are allowed to consult old lab reports but the submitted work should be original and it should be your own work.

The lab report for this week will be an **Informal Lab Report.** It is only necessary to turn in Section 4 as this week's lab report. The report will **due the next time your lab meets: 9–15 April**.

1 Introduction

This lab concentrates on the use of two MATLAB GUIs for convolution:

1. **`dconvdemo`:** GUI for discrete-time convolution. This is exactly the same as the MATLAB functions `conv()` and `firfilt()` used to implement FIR filters.

2. **`cconvdemo`:** GUI for continuous-time convolution.

$$y(t) = x(t) * h(t) = \int_{-\infty}^{\infty} x(\tau)h(t-\tau)d\tau = h(t) * x(t) = \int_{-\infty}^{\infty} h(\tau)x(t-\tau)d\tau \qquad (1)$$

Each one of these demos illustrates an important point about the behavior of a linear, time-invariant (LTI) system. They also provide a convenient way to visualize the output of a LTI system.

Both of these demos are available in the *SP-First* Toolbox, or they can be downloaded from the following web page:

`http://users.ece.gatech.edu/mcclella/matlabGUIs/index.html`

2 Pre-Lab: Run the Convolution GUIs

Several GUIs have been introduced during lectures over the past few weeks. The first objective of this lab is to demonstrate usage of two convolution GUIs.

2.1 Discrete-Time Convolution Demo

In this demo, you can select an input signal $x[n]$, as well as the impulse response of the filter $h[n]$. Then the demo shows the "flipping and shifting" used when a convolution is computed. This corresponds to the sliding window of the FIR filter. Figure 1 shows the interface for the `dconvdemo` GUI.

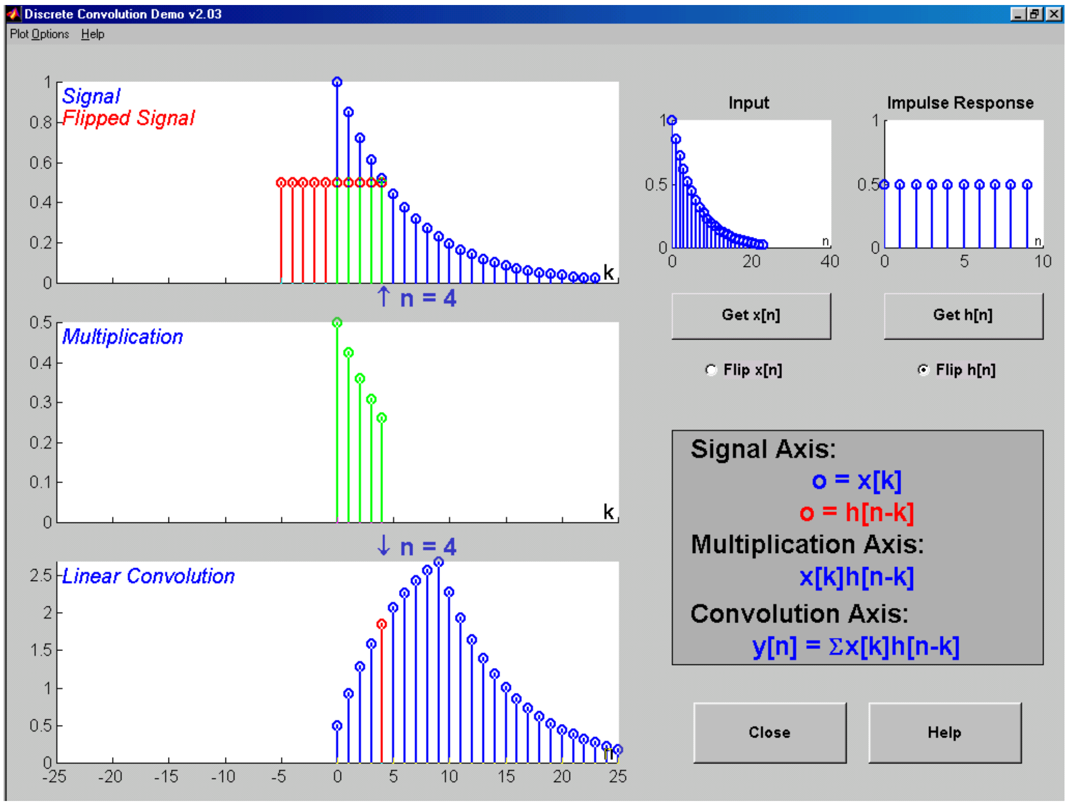

Figure 1: Interface for the discrete-time convolution GUI **`dconvdemo`**.

In the pre-Lab, you should perform the following steps with the `dconvdemo` GUI.

(a) Set the input to a finite-length pulse: $x[n] = 2\{u[n] - u[n-10]\}$.

(b) Set the filter's impulse response to obtain a five-point averager.

(c) Use the GUI to produce the output signal.

(d) When you move the mouse pointer over the index "n" below the signal plot and do a click-hold, you will get a *hand tool* that allows you to move the "n"-pointer. By moving the pointer horizontally you can observe the sliding window action of convolution. You can even move the index beyond the limits of the window and the plot will scroll over to align with "n."

(e) Set the filter's impulse response to a length-10 averager, i.e., $h[n] = \frac{1}{10}\{u[n] - u[n-10]\}$. Use the GUI to produce the output signal.

(f) Set the filter's impulse response to a shifted impulse, i.e., $h[n] = \delta[n-3]$. Use the GUI to produce the output signal.

(g) Compare the outputs from parts (c), (e) and (f). Notice the different shapes (triangle, rectangle or trapezoid), the maximum values, and the different lengths of the outputs.

2.2 Continuous-Time Convolution Demo

In this demo, you can select an input signal $x(t)$, as well as the impulse response of an **ANALOG** filter $h(t)$. Then the demo shows the "flipping and shifting" used when a convolution integral is performed. Figure 2 shows the interface for the `cconvdemo` GUI.

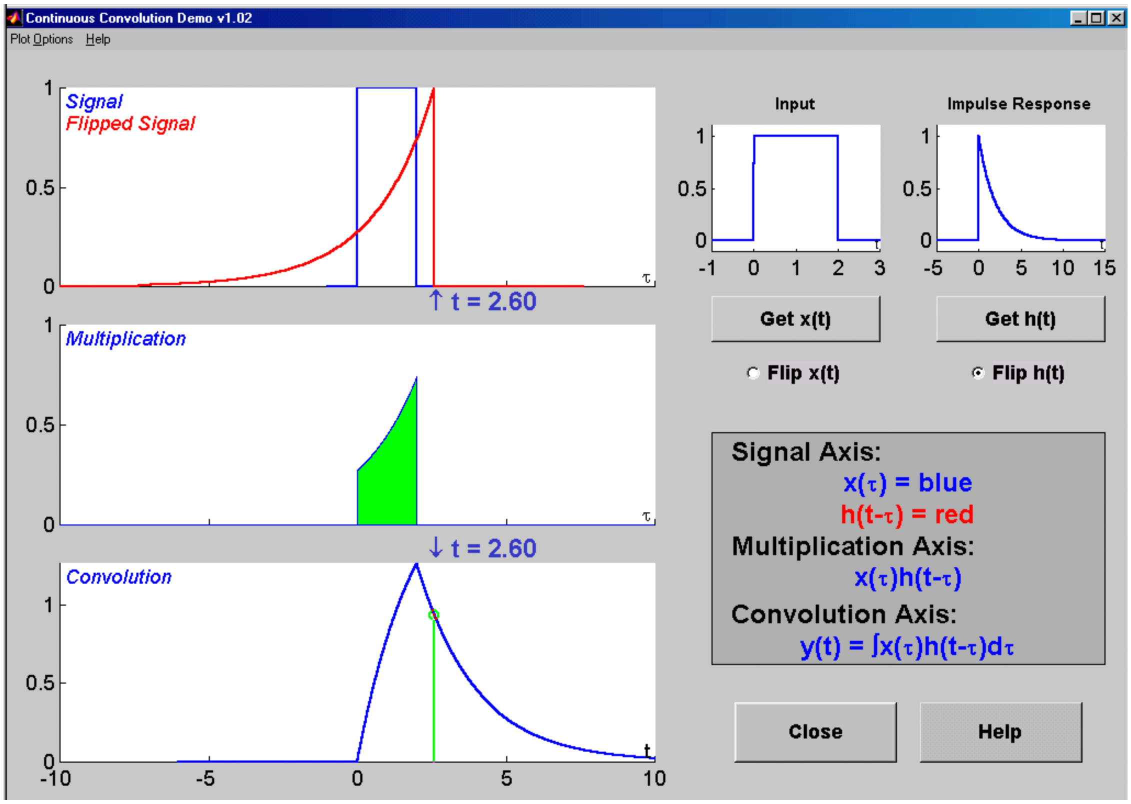

Figure 2: Interface for the continuous-time convolution GUI **cconvdemo**.

In the Pre-Lab, you should perform the following steps with the `cconvdemo` GUI.

(a) Set the input to a 4-second pulse $x(t) = u(t) - u(t-4)$.

(b) Set the filter's impulse response to a 2-second pulse with amplitude $\frac{1}{2}$, i.e., $h(t) = \frac{1}{2}\{u(t) - u(t-2)\}$.

(c) Use the GUI to produce the output signal. Use the *sliding hand tool* to grab the time marker and move it to produce the flip-and-slide effect of convolution.

(d) Set the filter's impulse response to a 4-second pulse with amplitude $\frac{1}{4}$, i.e., $h(t) = \frac{1}{4}\{u(t) - u(t-4)\}$. Use the GUI to produce the output signal.

(e) Set the filter's impulse response to a shifted impulse, i.e., $h(t) = \delta(t-3)$. Use the GUI to produce the output signal.

(f) Compare the outputs from parts (c), (d) and (e). Notice the different shapes (triangle, rectangle or trapezoid), the maximum values, and the different lengths of the outputs.

3 Warm-up: Compute Convolutions with the GUIs

The objective of the warm-up in this lab is to use the two convolution GUIs to solve problems (some of which are homework problems). Write down your observations on the *Verification Sheet.*

3.1 Continuous-Time Convolution GUI

In the warm-up, you should perform the following steps with the `cconvdemo` GUI.

(a) Set the input to an exponential: $x(t) = e^{-0.25t}\,\{u(t) - u(t-7)\}$.

(b) Set the filter's impulse response to a different exponential: $h(t) = e^{-0.55t}\,\{u(t+1) - u(t-3)\}$.

(c) Use the GUI to produce a plot of the output signal. Use the *sliding hand tool* to grab the time marker and move it to produce the flip-and-slide effect of convolution. Note: if you move the hand tool past the end of the plot, the plot will automatically scroll in that direction.

(d) The top panel is a plot of $x(\tau)$, and the middle panel shows the "flipped" impulse response $h(t-\tau)$ used to produce the "flip and slide" effect of convolution. The top two plots are functions of τ, while the bottom plot of $y(t)$ is a function of t. Observe that the output $y(t)$ is composed of five distinct regions: no overlap (on the left side), partial overlap (on the left side), complete overlap, partial overlap (on the right side), and no overlap (on the right side). If you substitute $x(t)$ and $h(t)$ from from parts (a) and (b) into Eq. (1), you can show that the output is given by the piecewise equation

$$y(t) = \begin{cases} 0 & t < T_0 & \mathit{Region}\ 1 \\ \displaystyle\int_{L_1}^{L_2} e^{-0.55\tau} e^{-0.25(t-\tau)} d\tau & T_1 \le t < T_2 & \mathit{Region}\ 2 \\ \displaystyle\int_{L_3}^{L_4} e^{-0.55\tau} e^{-0.25(t-\tau)} d\tau & T_3 \le t < T_4 & \mathit{Region}\ 3 \\ \displaystyle\int_{L_5}^{L_6} e^{-0.55\tau} e^{-0.25(t-\tau)} d\tau & T_5 \le t < T_6 & \mathit{Region}\ 4 \\ 0 & T_7 \le t & \mathit{Region}\ 5 \end{cases} \tag{2}$$

Use the GUI to observe that $y(t)$ does indeed have five distinct regions, and use it to help you figure out the values for the boundaries of the regions and the limits of integration for each part. Determine whether you are flipping $x(t)$ or $h(t)$. *Hint: The limits of integration might depend on the variable t.*

Instructor Verification (separate page)

3.2 Discrete-Time Convolution GUI

In the warm-up, you should perform the following steps with the `dconvdemo` GUI.

(a) Set the input to a finite-length sinusoid: $x[n] = 2\cos(2\pi(n-2)/3)\,(u[n-2] - u[n-20])$.

(b) Set the filter's impulse response to obtain a 3-point averager.

(c) Use the GUI to produce the output signal.

(d) Explain why the output has five different regions and why the output is zero in three of the five.

Instructor Verification (separate page)

4 Lab Exercises

In each of the following exercises, you should make a screen shot of the final picture produced by the GUI to validate that you were able to do the implementation. In all cases, you will have to do some mathematical calculations to verify that the MATLAB GUI result is correct.

4.1 Continuous-Time Convolution

In this section, use the continuous-time convolution GUI, `cconvdemo`, to do the following:

(a) Set the input to an exponential: $x(t) = e^{-0.75(t-1)}\{u(t-1) - u(t-4)\}$.

(b) Set the filter's impulse response to a different exponential: $h(t) = e^{0.1t}\{u(t) - u(t-5)\}$.

(c) Use the GUI to produce a plot of the output signal, $y(t)$. Include the plot in your report.

(d) Determine the boundaries of all five regions for $y(t)$, i.e., the starting and ending times in secs.

(e) Determine the mathematical formula for the convolution in each of the five regions. Use the GUI to help in setting up the integrals, but carry out the mathematics of the integrals by hand.

4.2 Continuous-Time Convolution: Transient and Steady State

(a) Find the output of an analog filter whose impulse response is

$$h(t) = u(t-5) - u(t)$$

when the input is

$$x(t) = 2\sin(0.4\pi t)\{u(t) - u(t-20)\}$$

(b) Use the GUI to determine the length of the output signal and the boundaries of the five regions of the convolution.
Note: the regions of partial overlap would be called *transient regions* while the region of complete overlap would be the *steady state region.*

(c) Perform the mathematics of the convolution integral to get the *exact analytic form* of the output signal and verify that the GUI is correct. Also verify that the starting and ending times of the output signal are correct.

4.3 Discrete-Time Convolution: Transient and Steady State

Use the discrete-time convolution GUI, `dconvdemo`, to do the following:

(a) Find the output of a digital filter whose impulse response is $h[n] = u[n-5] - u[n]$
when the input is $x[n] = 2\sin(0.4\pi n)\{u[n] - u[n-20]\}$

(b) Use the GUI to determine the length of the output signal and notice that you can see five regions just like for the continuous-time convolution.
Note: the regions of partial overlap would be called *transient regions* while the region of complete overlap would be the *steady state region.*

(c) Use numerical convolution to get the exact values of the output signal for each of the five regions. Thus, you will verify that the GUI is correct. Also verify that the duration of the output signal is correct.

(d) Discuss the relationship between this output and the continuous-time output signal in Section 4.2. Point out similarities and differences. For example, does the same formula govern $y[n]$ and $y(t)$, so that $y[n]$ is equal to a sampled version of $y(t)$ from Section 4.2?

Lab #11
ECE-2025
Spring-2003
INSTRUCTOR VERIFICATION PAGE

For each verification, be prepared to explain your answer and respond to other related questions that the lab TA's or professors might ask. Turn this page in at the end of your lab period.

Name: ____ Date of Lab: __________

Part 3.1: Demonstrate that you can run the continuous-time convolution demo. Explain how to find the FIVE regions for this convolution integral. Use the plots of $x(\tau)$ and $h(t-\tau)$ together with the corresponding plot of $y(t)$ to complete the following table with the correct values for the time region boundaries and integral limits in Eq. (2).

	$T_0 =$			Region 1
$T_1 =$	$T_2 =$	$L_1 =$	$L_2 =$	Region 2
$T_3 =$	$T_4 =$	$L_3 =$	$L_4 =$	Region 3
$T_5 =$	$T_6 =$	$L_5 =$	$L_6 =$	Region 4
	$T_7 =$			Region 5

Observe that $y(t)$ is zero for $t < T_0$ and for $t \geq T_7$. If T_a and T_b are the starting and ending times of $x(t)$ and T_c and T_d are the starting and ending times of $h(t)$, how are T_0 and T_7 related to the starting and ending times of $x(t)$ and $h(t)$?

Note that the area under the curve in the middle plot is shaded green. When you set the time indicator to $t = 5$, how is the shaded area related to $y(5)$?

What did you observe when you flipped $x(t)$ instead of $h(t)$? Which of the following properties of convolution does this illustrate?
linearity time-invariance causality associativity commutativity stability

Explain the above answers to your TA. Verified:____________________ Date/Time:__________

Part 3.2: Demonstrate that you can run the discrete-time convolution demo. Explain why the output is zero in three of the five regions identified for the output signal.

Verified:____________________ Date/Time:__________